Laboratory 1 (w3-4)

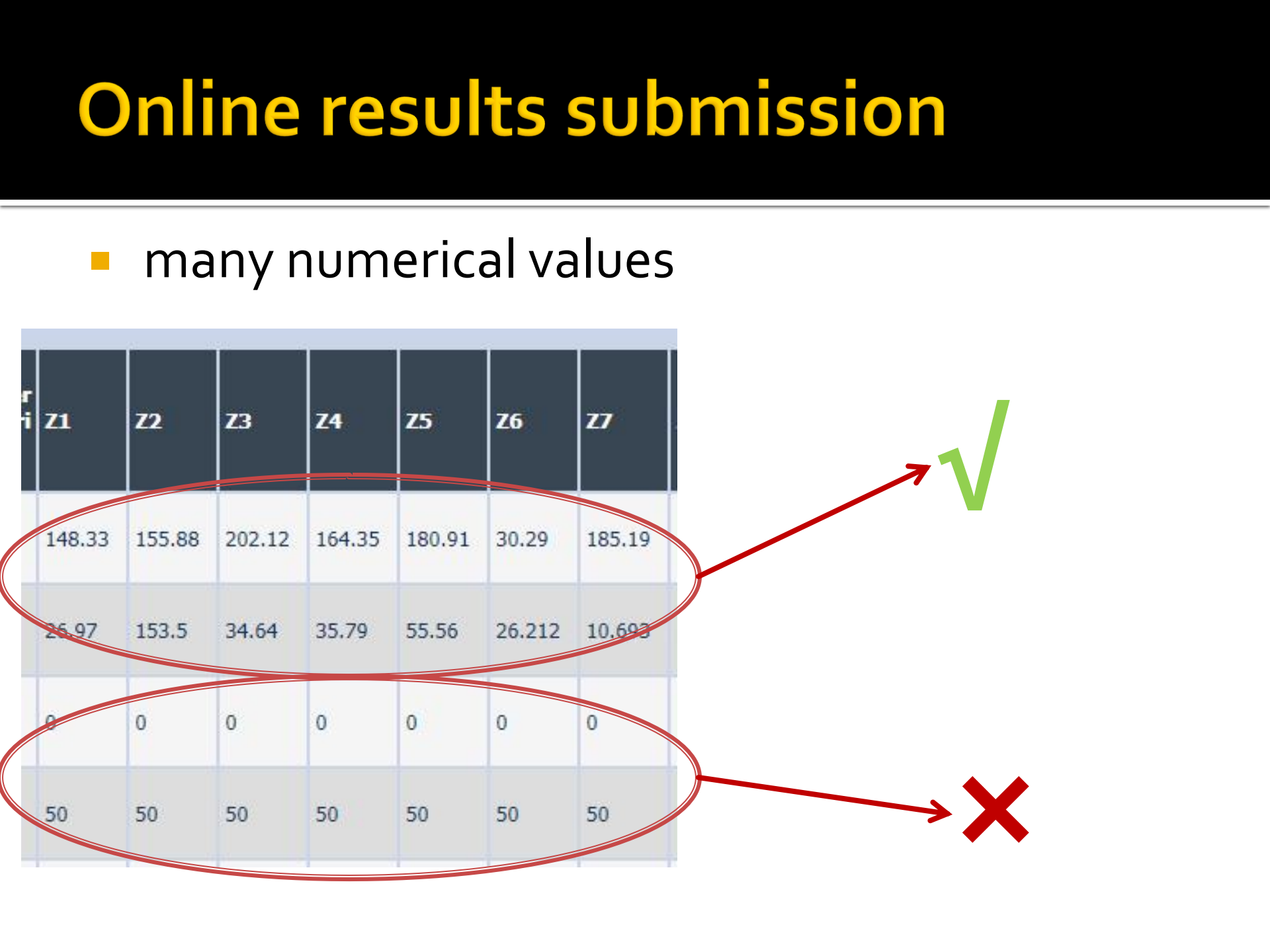
2021/2022

Microwave Devices and Circuits

Online results submission

- many numerical values

Z1	Z2	Z3	Z4	Z5	Z6	Z7
148.33	155.88	202.12	164.35	180.91	30.29	185.19
26.97	153.5	34.64	35.79	55.56	26.212	10.693
0	0	0	0	0	0	0
50	50	50	50	50	50	50



Online results submission

Grade = Quality of the work +

+ Quality of the submission

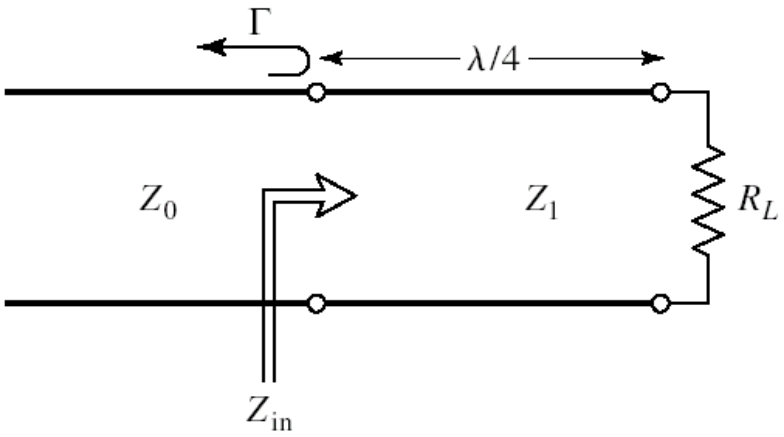
Short theory

Impedance matching

- Impedance matching is required when we have an abrupt change of the impedance or characteristic impedance (transmission lines)
- The quality of the match is denoted by the value of the reflection coefficient (Γ)
  - $|\Gamma|=0$ perfect match
  - $|\Gamma|\approx 0$, $|\Gamma|<\Gamma_{max}$ "good enough" match
- in ADS: $|\Gamma|==|S11|$

The quarter-wave transformer

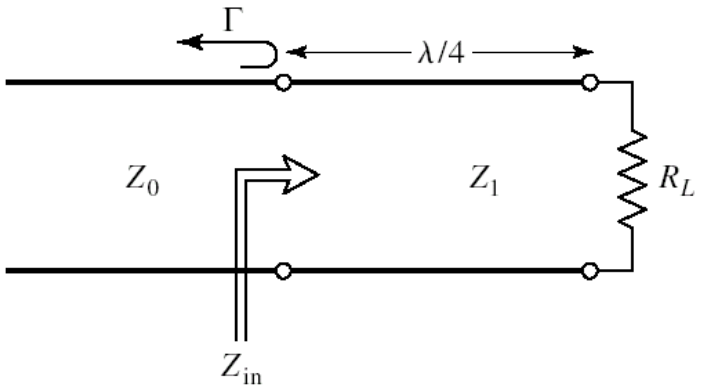
- Feed line – input line with characteristic impedance Z_0
- (**Real!**) load impedance R_L
- We desire matching the load to the fider with a second line with the length **λ/4** and characteristic impedance Z_1



$$\Gamma_{in} = 0 \quad \Rightarrow \quad Z_1 = \sqrt{Z_0 R_L}$$

$$Z_{in} = Z_1 \frac{R_L + jZ_1 \tan(\beta l)}{Z_1 + jR_L \tan(\beta l)}$$

The quarter-wave transformer



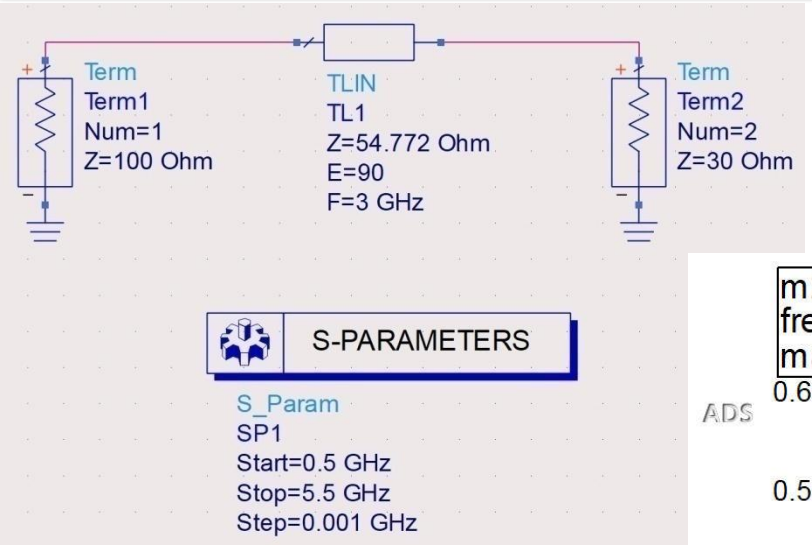
$$\Gamma_{in} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0}$$

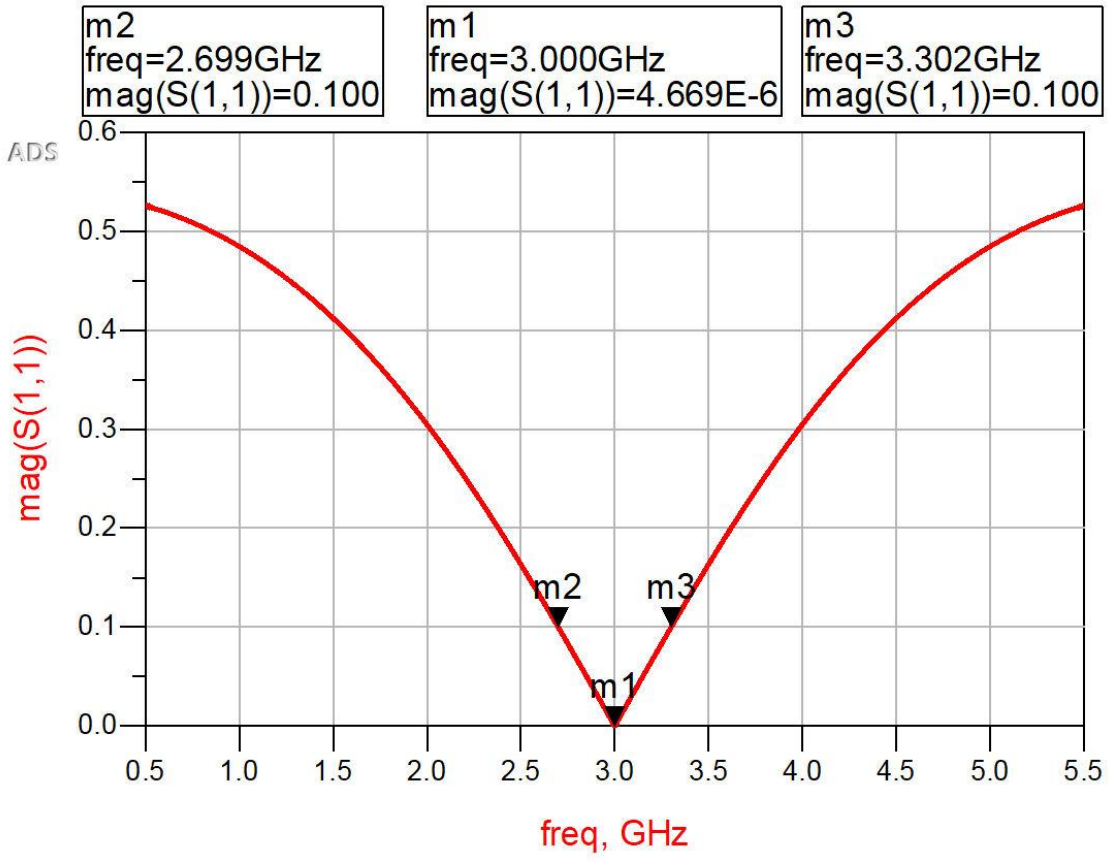
$$\beta \cdot l = \frac{2\pi}{\lambda} \cdot \frac{\lambda}{4} = \frac{\pi}{2} \qquad Z_{in} = \frac{Z_1^2}{R_L}$$

$$\Gamma_{in} = \frac{Z_1^2 - Z_0 \cdot R_L}{Z_1^2 + Z_0 \cdot R_L} \qquad \Gamma_{in} = 0 \Rightarrow Z_1 = \sqrt{Z_0 R_L}$$

- In the feed line (Z_o) we have only progressive wave
- In the quarter-wave line (Z_1) we have standing waves

The quarter-wave transformer

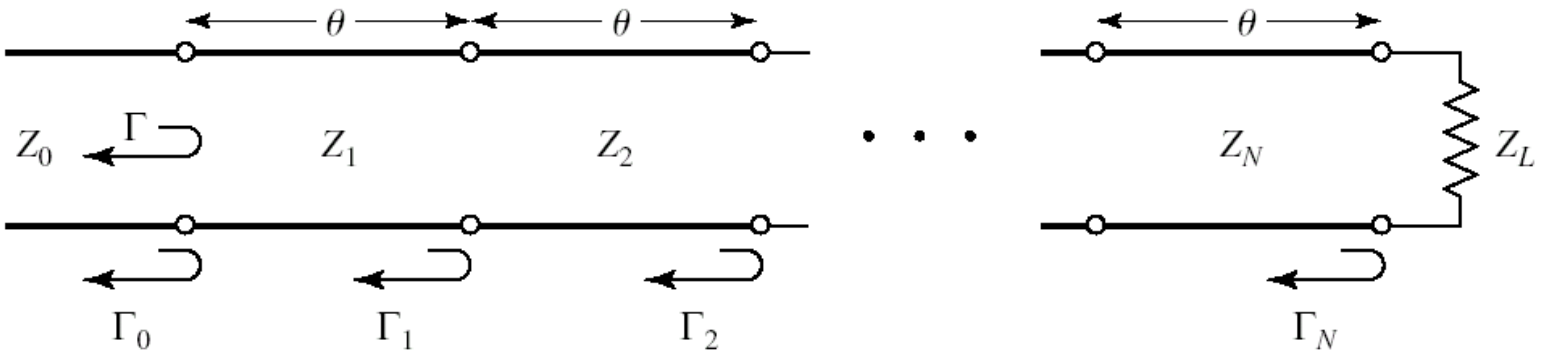




Multisection Impedance Transformer

- The quarter-wave transformer can match any real load to any feed line impedance
- If a greater bandwidth for the match is required we must use multiple sections of transmission lines transformers:
  - binomial
  - Chebyshev

Multisection Impedance Transformers



- We assume that all impedances **increase or decrease monotonically** across the transformer
- This implies that all reflection coefficients will be real and of the same sign
- Previously, 1 section $\Gamma \cong \Gamma_1 + \Gamma_3 \cdot e^{-2j\theta} \Rightarrow$

$$\Gamma(\theta) = \Gamma_0 + \Gamma_1 \cdot e^{-2j\theta} + \Gamma_2 \cdot e^{-4j\theta} + \cdots + \Gamma_N \cdot e^{-2jN\theta}$$

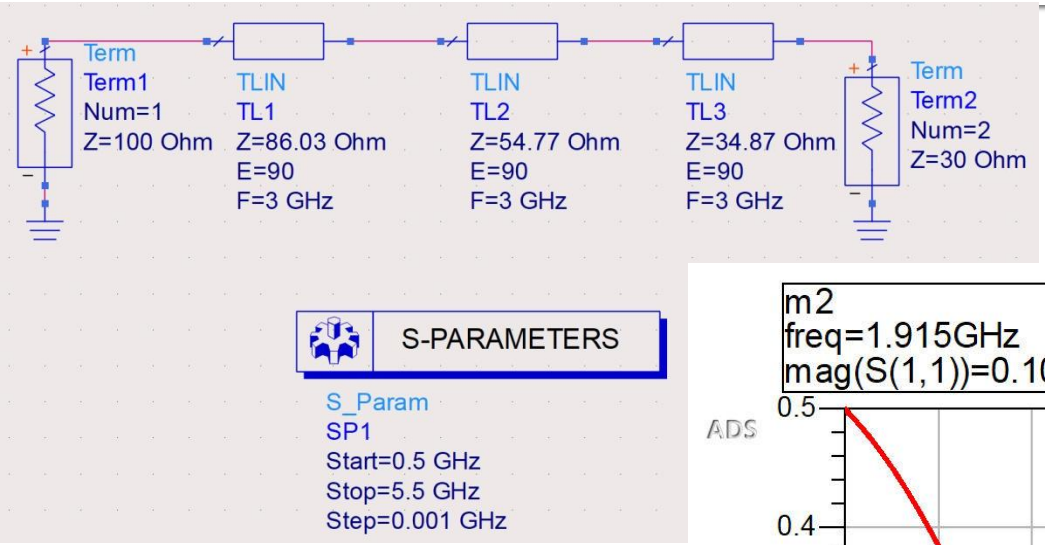
$$\Gamma_1 = \frac{Z_1 - Z_0}{Z_1 + Z_0}$$

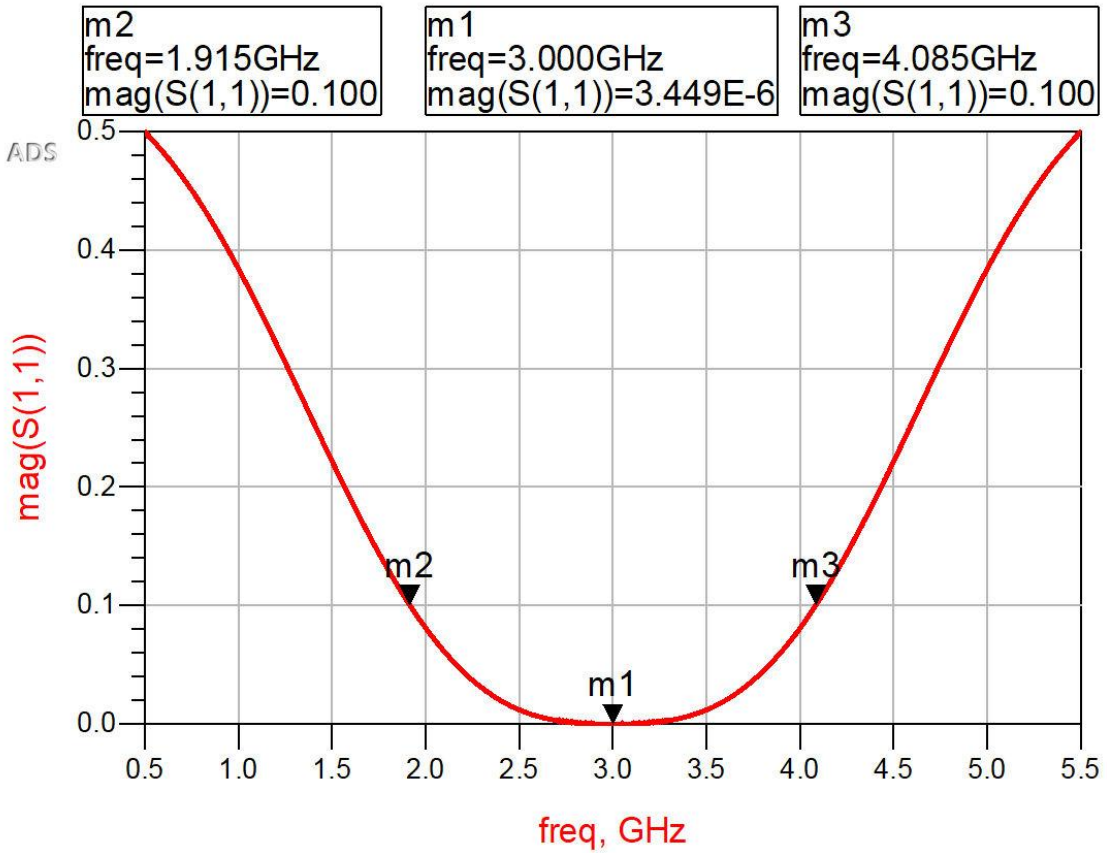
$$\Gamma_n = \frac{Z_{n+1} - Z_n}{Z_{n+1} + Z_n}$$

$$n = \overline{1, N-1}$$

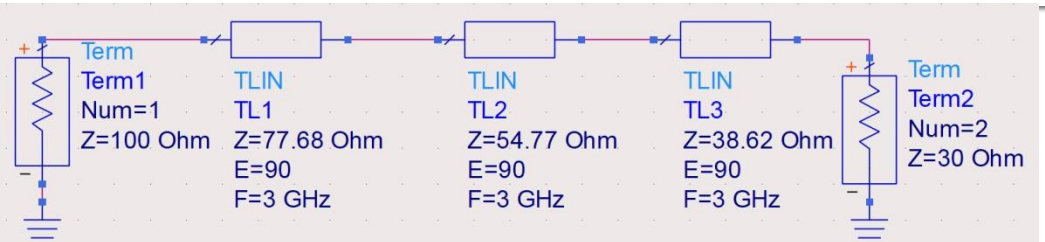
$$\Gamma_N = \frac{Z_L - Z_N}{Z_L + Z_N}$$

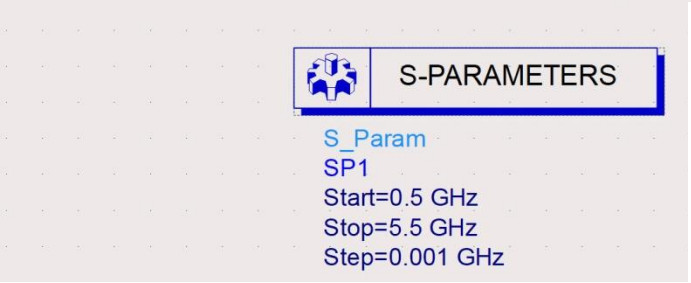
Binomial

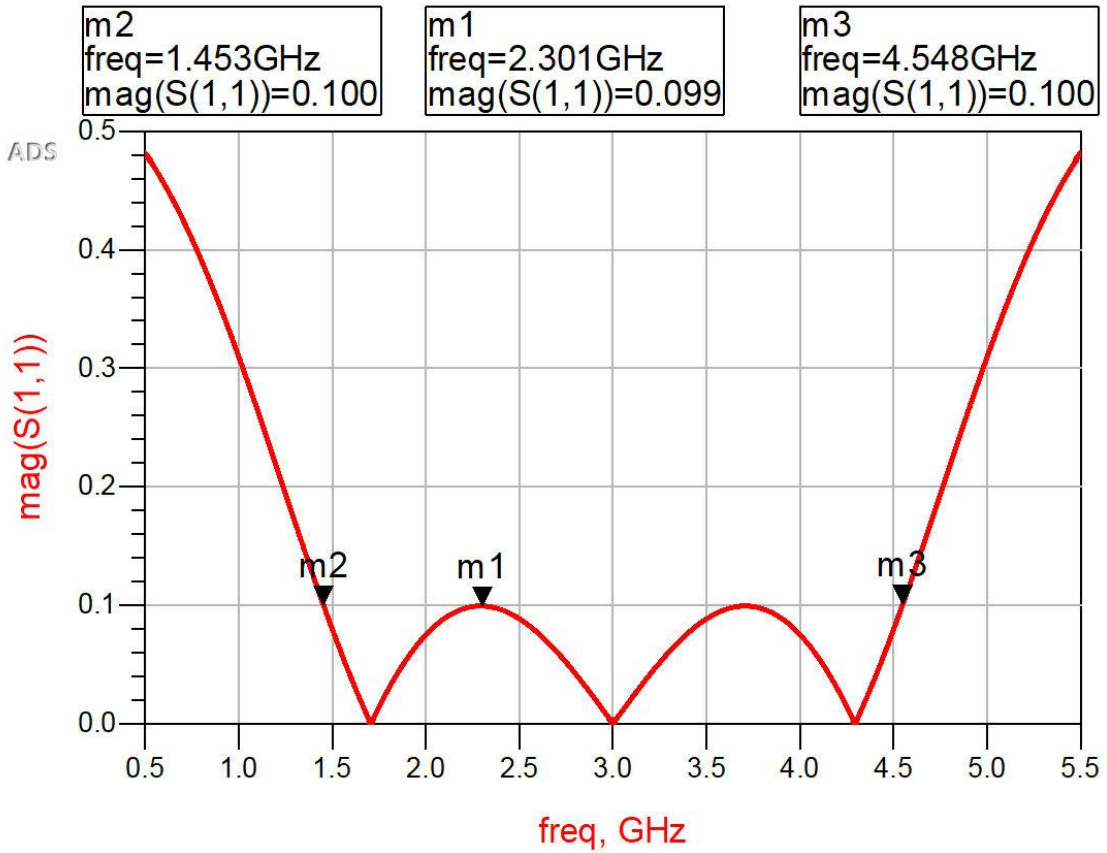

Term
Term1
Num=1
Z=100 Ohm
TLIN
TL1
Z=86.03 Ohm
E=90
F=3 GHz
TLIN
TL2
Z=54.77 Ohm
E=90
F=3 GHz
TLIN
TL3
Z=34.87 Ohm
E=90
F=3 GHz
Term
Term2
Num=2
Z=30 Ohm
S-PARAMETERS
S_Param
SP1
Start=0.5 GHz
Stop=5.5 GHz
Step=0.001 GHz


m2
freq=1.915GHz
mag(S(1,1))=0.100
m1
freq=3.000GHz
mag(S(1,1))=3.449E-6
m3
freq=4.085GHz
mag(S(1,1))=0.100
ADS
mag(S(1,1))
freq, GHz
0.0
0.1
0.2
0.3
0.4
0.5
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
m1
m2
m3

Chebyshev

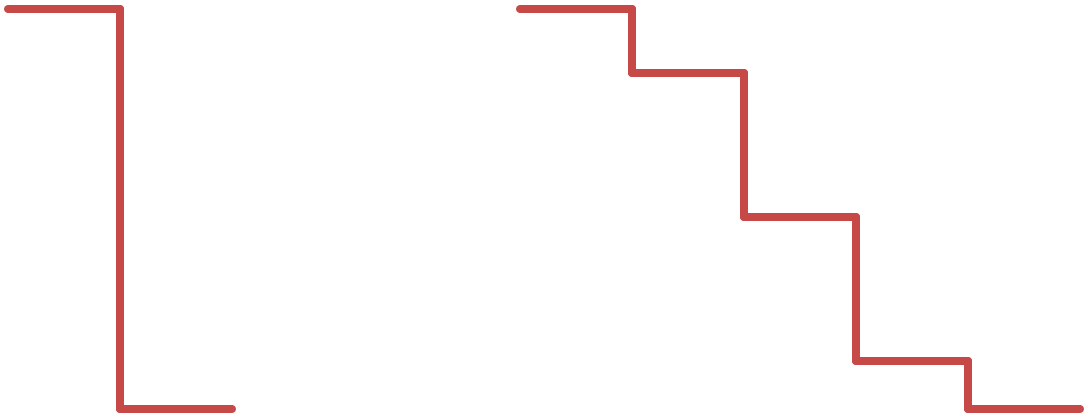

Term
Term1
Num=1
Z=100 Ohm
TLIN
TL1
Z=77.68 Ohm
E=90
F=3 GHz
TLIN
TL2
Z=54.77 Ohm
E=90
F=3 GHz
TLIN
TL3
Z=38.62 Ohm
E=90
F=3 GHz
Term
Term2
Num=2
Z=30 Ohm


S-PARAMETERS
S_Param
SP1
Start=0.5 GHz
Stop=5.5 GHz
Step=0.001 GHz


m2
freq=1.453GHz
mag(S(1,1))=0.100
m1
freq=2.301GHz
mag(S(1,1))=0.099
m3
freq=4.548GHz
mag(S(1,1))=0.100
ADS
mag(S(1,1))
freq, GHz
0.0
0.1
0.2
0.3
0.4
0.5
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
m2
m1
m3

Impedance matching

- In principle we replace an **abrupt change** of the impedance value with a **step by step change** of the impedance value, with smaller steps
- The increase/decrease steps must be carefully designed for good results



Practical Procedure

Step 0

- Write by hand on a sheet of paper 100 times:
- **I solemnly promise to read the text AND NOT to jump from picture to picture**
- ☺

Step 1

- Identify which one of the received impedance values will be Zo and which one will be Z_L in formulas (in order to use the design tables)
- Use as **Z_o the smaller value** of the two values you received (source or load), and as **Z_L use the larger value**

Step 2

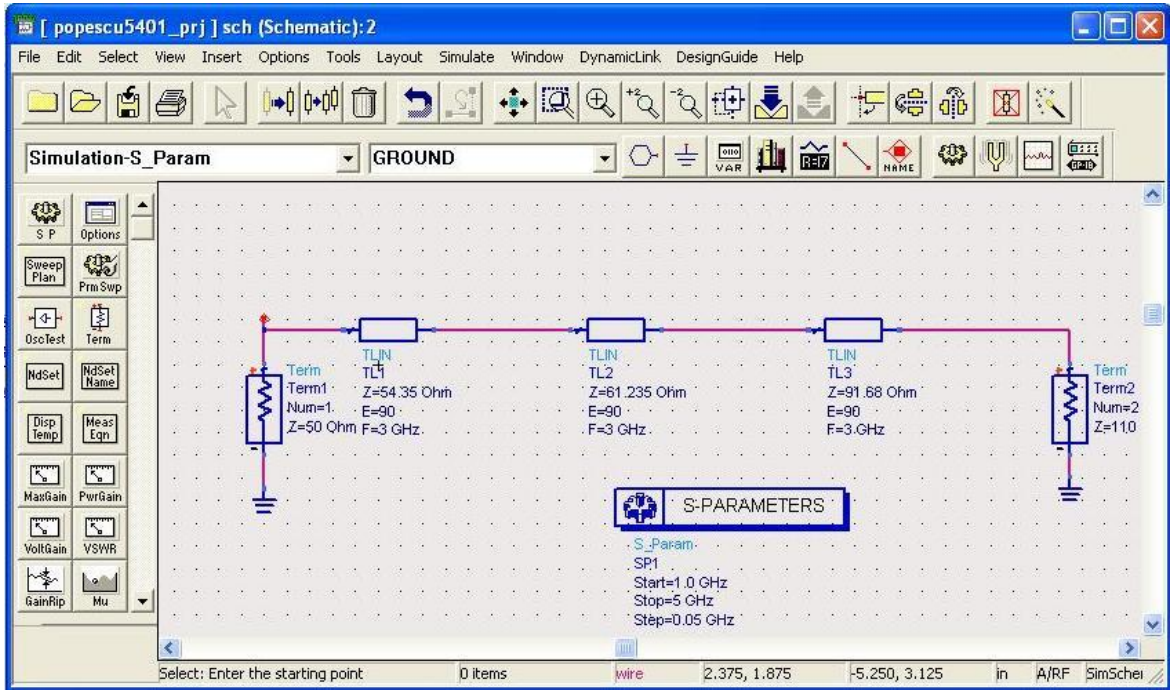
- Using the proper table (binomial) **compute** Z1, Z2, Z3
- !! If at step 1 you switched Zo and Z_L (meaning your individual subject has Z_L > Zo) switch also the order of the impedances you computed (eg. Z1 <-> Z3)

	$N = 2$		$N = 3$			$N = 4$			
Z_L/Z_0	Z_1/Z_0	Z_2/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_4/Z_0
1.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.5	1.1067	1.3554	1.0520	1.2247	1.4259	1.0257	1.1351	1.3215	1.4624
2.0	1.1892	1.6818	1.0907	1.4142	1.8337	1.0444	1.2421	1.6102	1.9150
3.0	1.3161	2.2795	1.1479	1.7321	2.6135	1.0718	1.4105	2.1269	2.7990
4.0	1.4142	2.8285	1.1907	2.0000	3.3594	1.0919	1.5442	2.5903	3.6633
6.0	1.5651	3.8336	1.2544	2.4495	4.7832	1.1215	1.7553	3.4182	5.3500
8.0	1.6818	4.7568	1.3022	2.8284	6.1434	1.1436	1.9232	4.1597	6.9955
10.0	1.7783	5.6233	1.3409	3.1623	7.4577	1.1613	2.0651	4.8424	8.6110

	$N = 5$					$N = 6$					
Z_L/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_4/Z_0	Z_5/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_4/Z_0	Z_5/Z_0	Z_6/Z_0
1.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.5	1.0128	1.0790	1.2247	1.3902	1.4810	1.0064	1.0454	1.1496	1.3048	1.4349	1.4905
2.0	1.0220	1.1391	1.4142	1.7558	1.9569	1.0110	1.0790	1.2693	1.5757	1.8536	1.9782
3.0	1.0354	1.2300	1.7321	2.4390	2.8974	1.0176	1.1288	1.4599	2.0549	2.6577	2.9481
4.0	1.0452	1.2995	2.0000	3.0781	3.8270	1.0225	1.1661	1.6129	2.4800	3.4302	3.9120
6.0	1.0596	1.4055	2.4495	4.2689	5.6625	1.0296	1.2219	1.8573	3.2305	4.9104	5.8275
8.0	1.0703	1.4870	2.8284	5.3800	7.4745	1.0349	1.2640	2.0539	3.8950	6.3291	7.7302
10.0	1.0789	1.5541	3.1623	6.4346	9.2687	1.0392	1.2982	2.2215	4.5015	7.7030	9.6228

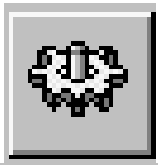
Step 3

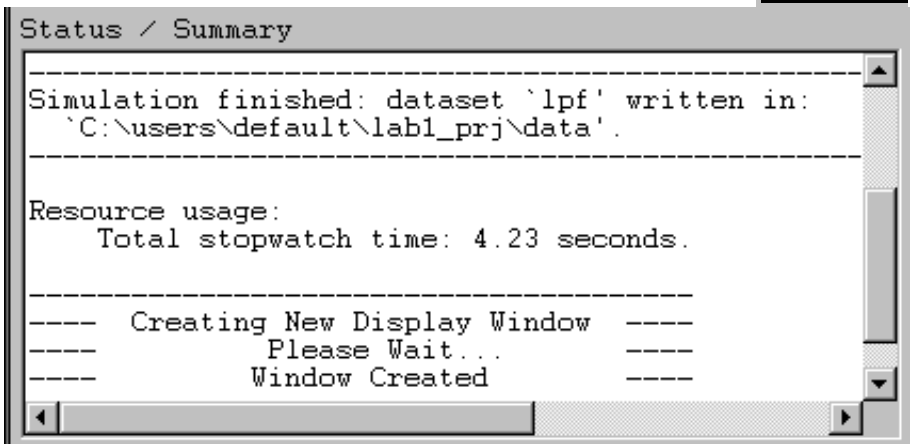
- Draw the schematic as instructed in the lab manual
- **Save it** with whatever name (~~untitled~~)



Step 4

- Start the simulation

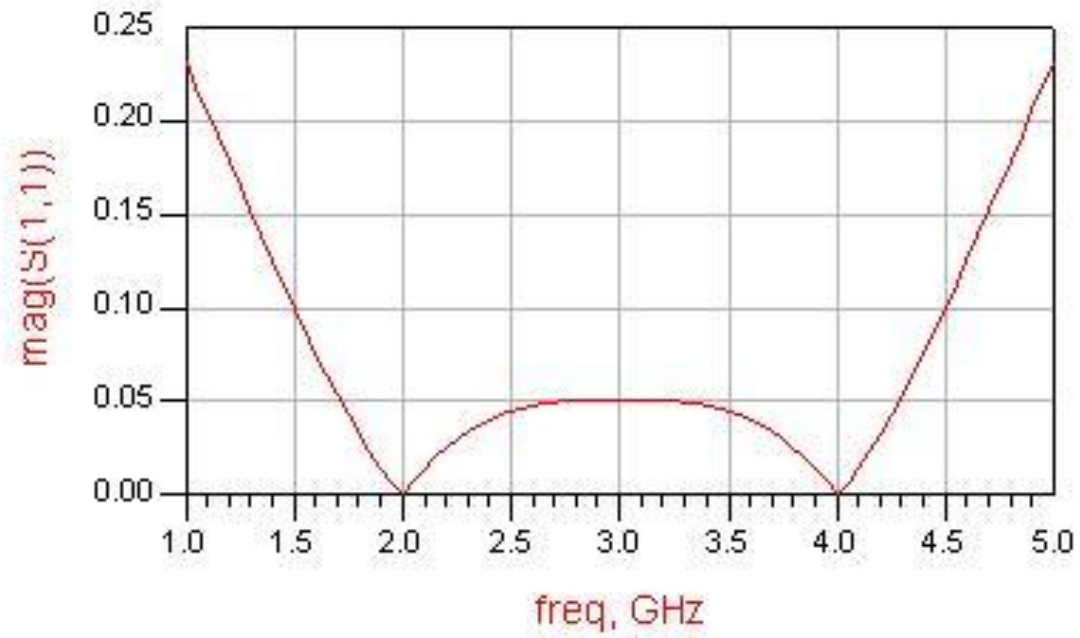




- Successful simulation will open a new window, for results report
  - the window will have the same file name (but a different extension) as the name you used when you saved the schematic

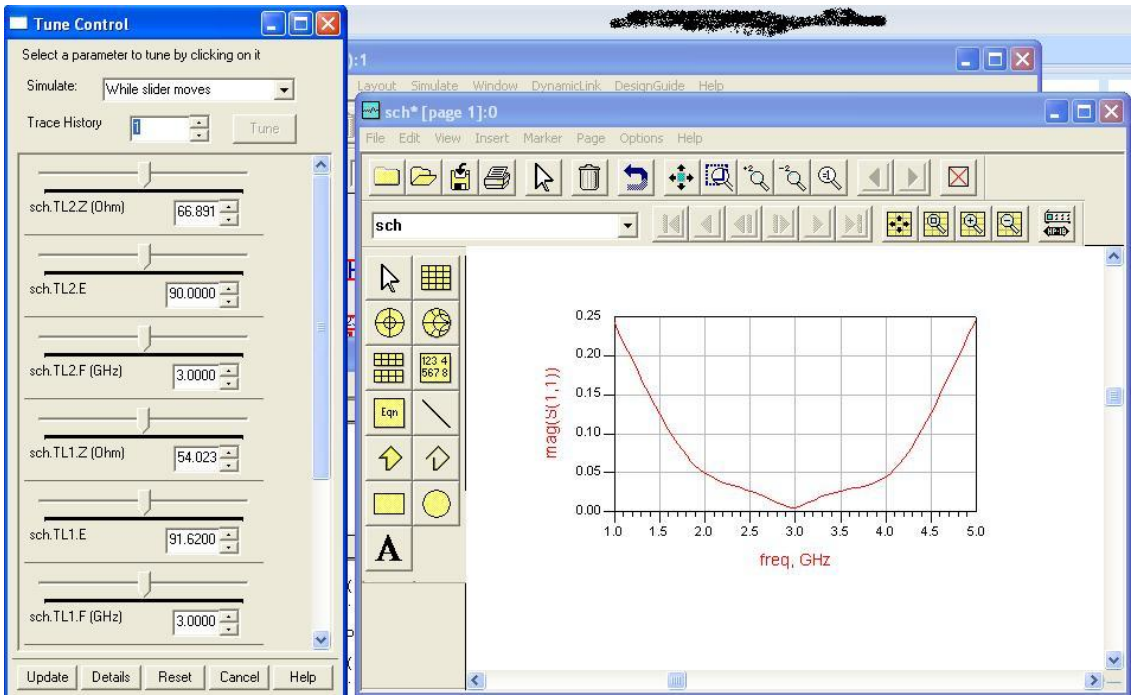
Step 5

- Insert the rectangular graph to plot the results
- Most likely you wont get the perfect results but they represent an intermediary step



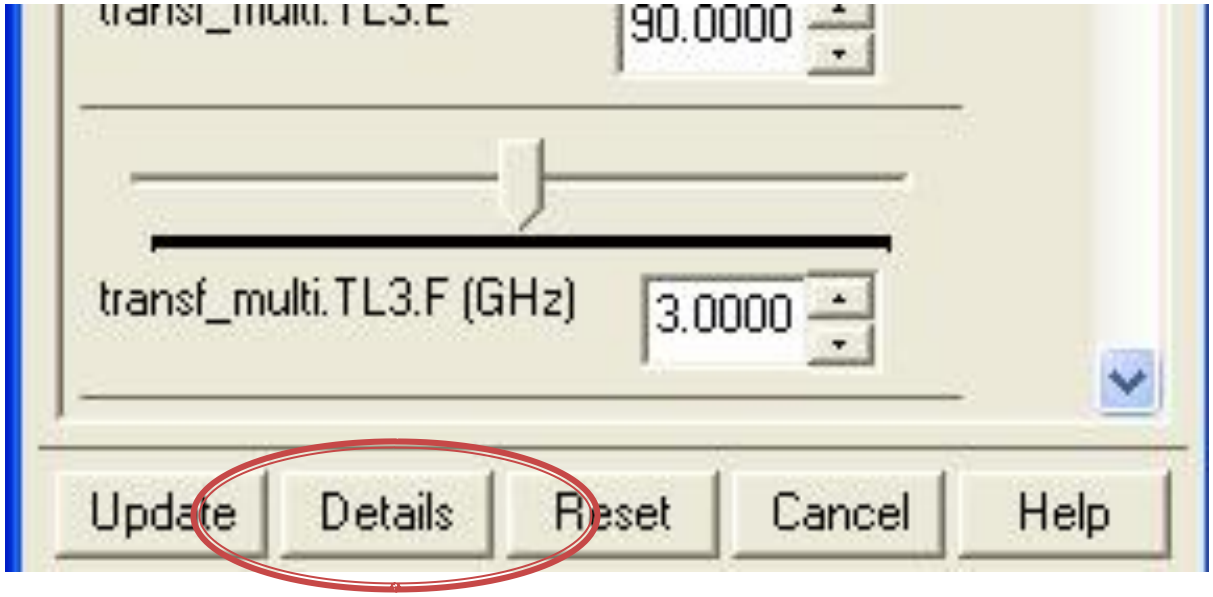
Step 6

- Start the **tune** tool
- Position the windows on the screen appropriately in order to see **in real time** the tune effect



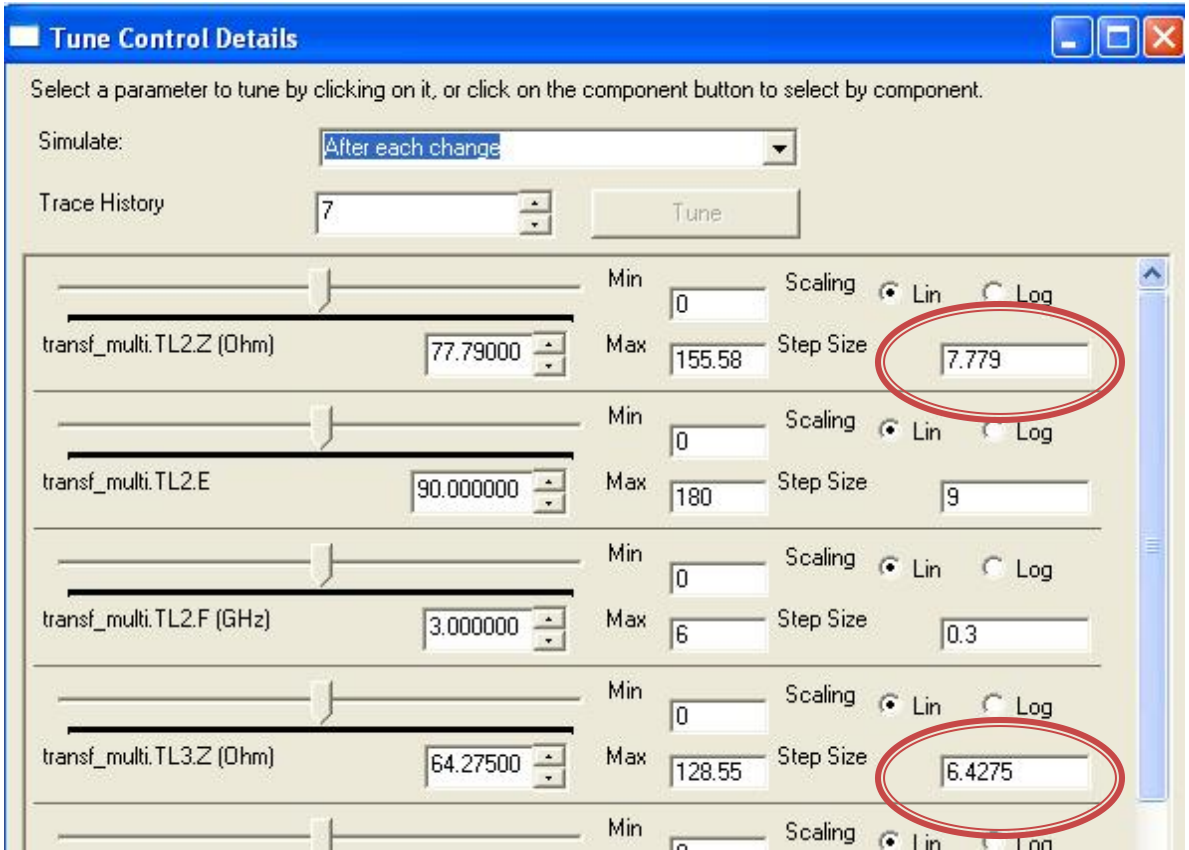
Step 7a

- If needed (most likely scenario) press “Details” on Tune Control and change the step size



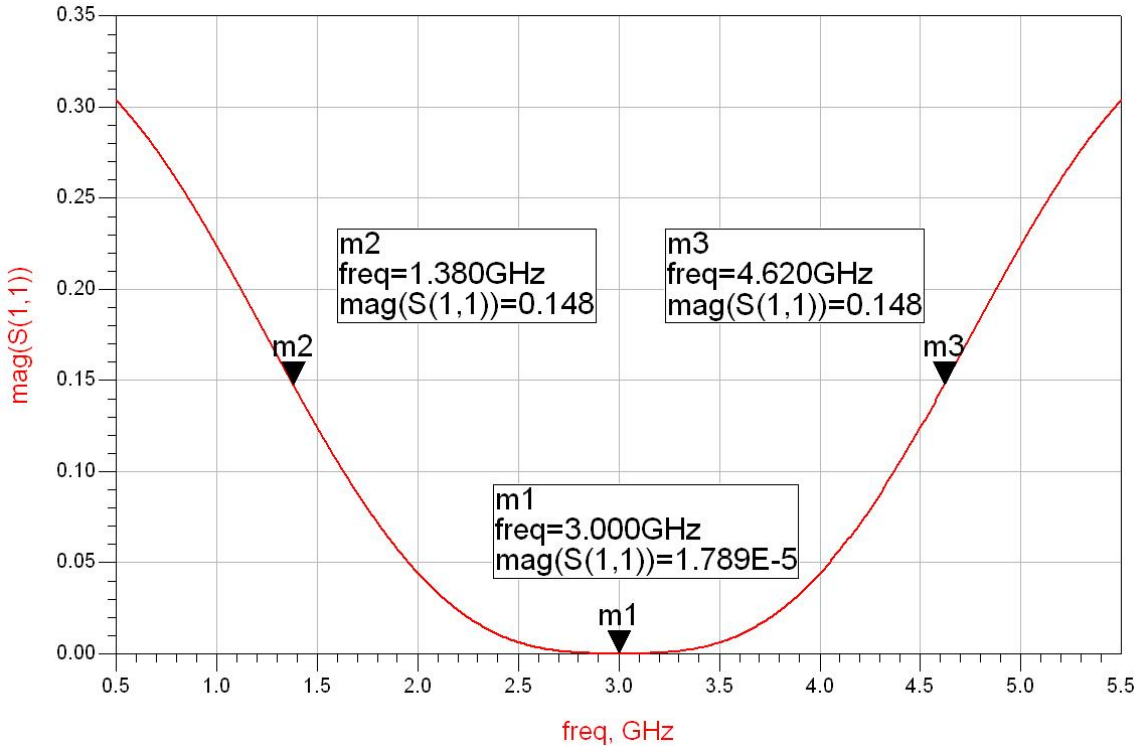
Step 7b

- Change the "Step Size" (! only for impedances)
  - 1, then 0.1, then 0.01 ….. (as required)



Step 8

- Finish the tune using smaller and smaller step size (1 > 0.1 > 0.01 ….) watching as the result approaches the desired one



Step 9

- When you are satisfied with the results press **"Update"** in Tune Control to send the tuned values to the schematic. **Save** the schematic again
- **Carefully write down** Z1, Z2, Z3 and the bandwidth as f1 and f2 (the limits of the bandwidth can be found using 1-2 markers in the points where |S11| equals Γ_{max} for your individual subject)

Step 10

- Save the schematic with a different name (**Save As**)
  - the schematic for Chebyshev transformer is the same, except the numerical values of the impedances, which will have to be replaced

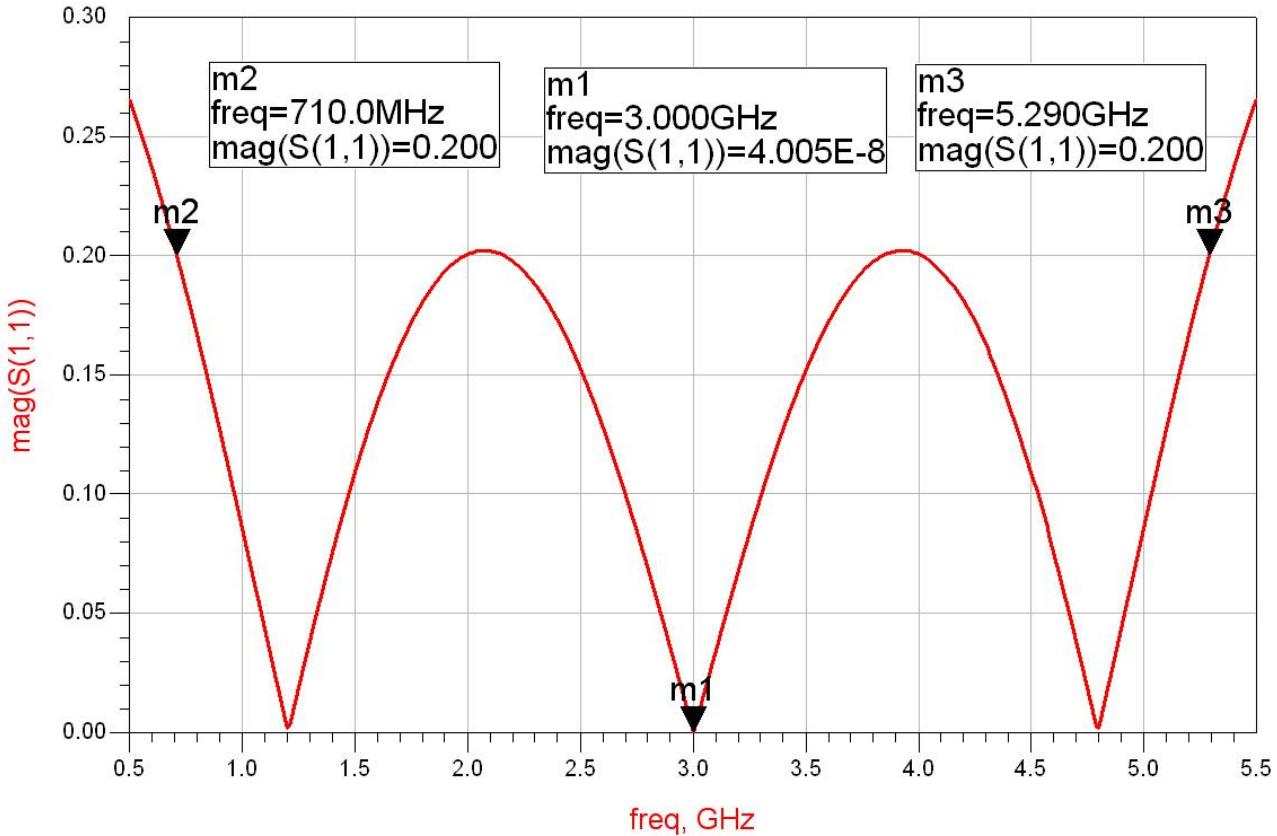
Steps 11 - 19

- **Repeat** steps 2-10 but using the table for Chebyshev transformer and targeting an **equiripple** result by **tuning**

	$N = 2$				$N = 3$					
	$\Gamma_m = 0.05$		$\Gamma_m = 0.20$		$\Gamma_m = 0.05$			$\Gamma_m = 0.20$		
Z_L/Z_0	Z_1/Z_0	Z_2/Z_0	Z_1/Z_0	Z_2/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0
1.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.5	1.1347	1.3219	1.2247	1.2247	1.1029	1.2247	1.3601	1.2247	1.2247	1.2247
2.0	1.2193	1.6402	1.3161	1.5197	1.1475	1.4142	1.7429	1.2855	1.4142	1.5558
3.0	1.3494	2.2232	1.4565	2.0598	1.2171	1.7321	2.4649	1.3743	1.7321	2.1829

Pas 20

- When satisfied with the results press Update, save the second schematic write down a second set of values Z1, Z2, Z3 and f1,f2



Pas 21

- **Carefully** fill in the input boxes in the on-line "exam" Laboratory 1 on the rf-opto server with the exact values you got (the **final tuned** ones not the initial computed ones)

Online results submission

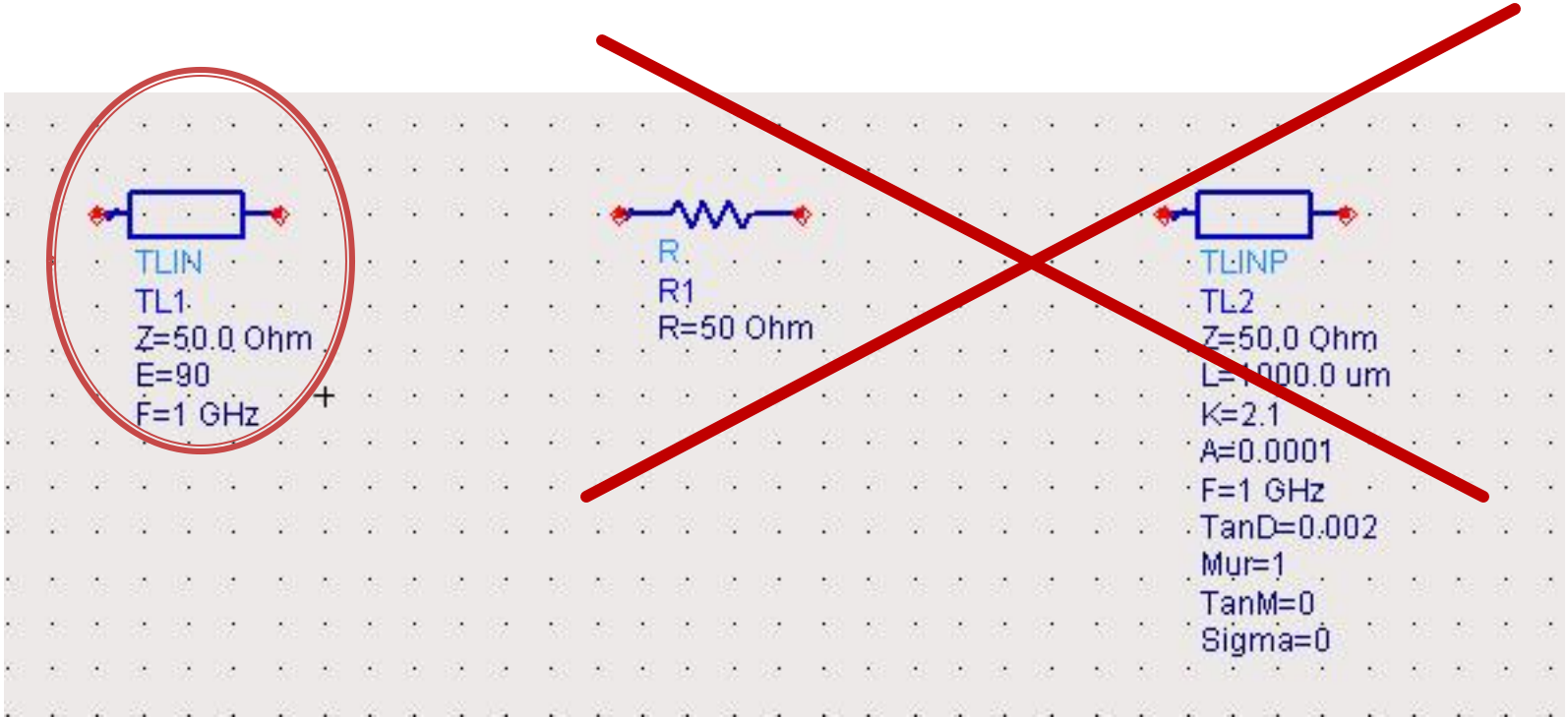
Grade = Quality of the work +

+ Quality of the submission

Frequent mistakes

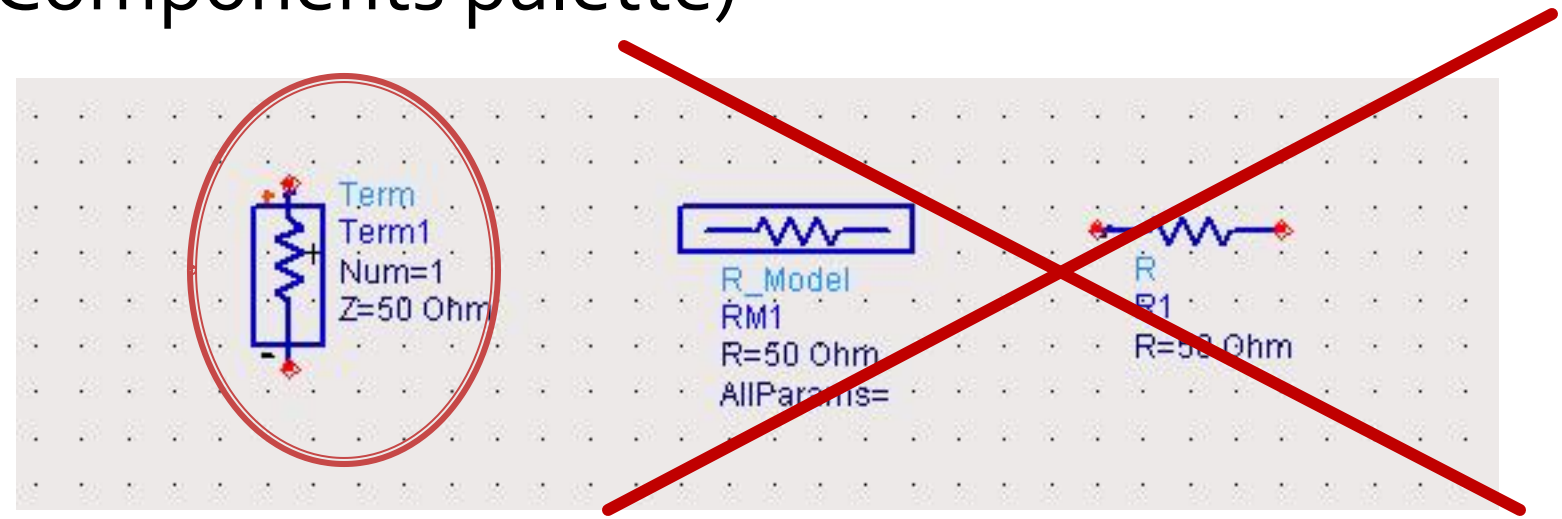
Mistakes 1

- Putting in the schematic instead of the ideal transmission lines (**TLIN**) resistors or other parts (microstrip, physical etc.)



Mistakes 2

- Putting in the schematic instead of terminators/ports (**TERM –Simulation S-param palette**) R_model or even R (Lumped Components palette)

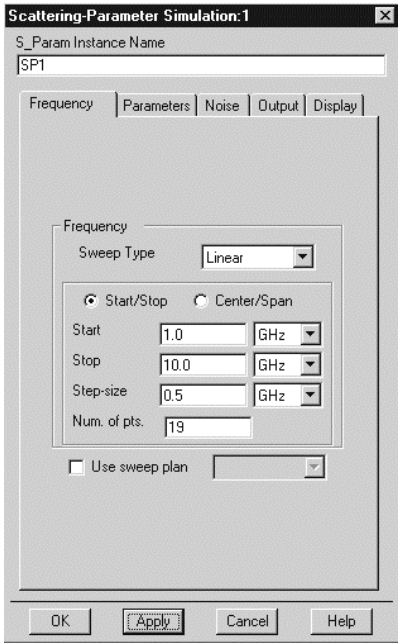


Mistakes 3

- **Forgetting** to change to the numerical values (from the individual subject) for terminators/ports/source/load (**TERM1** and **TERM2**)
- Forgetting to change the frequency to the one from the individual subject (**TLIN1, TLIN2, TLIN3**)
- Wrong order of the impedances (**! frequent**)
  - as a quick check (including during tune), all impedances **must increase or decrease monotonically** across the transformer (including source/load)

Mistakes 4

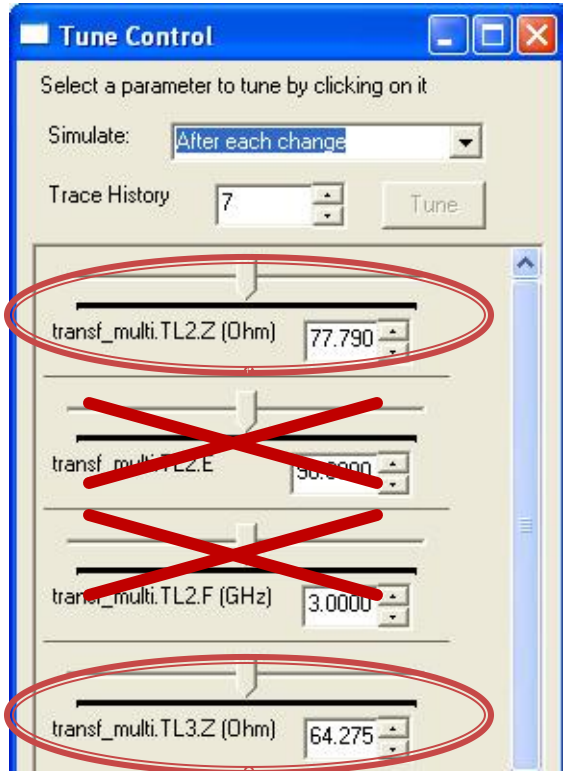
- Forgetting to change the parameters for the simulation
  - often **Start/Stop/Step size** stays at: **1GHz/10GHz/1GHz** (undesirable)



- **Start/Stop/Step size**: should be changed to **fo-Δf/fo+Δf/(0.05GHz or 0.01GHz)**
- where Δf is applied symmetrically around the imposed fo such as the matching bandwidth can be observed; if results show Δf was chosen too small, increase it and repeat simulation

Mistakes 5

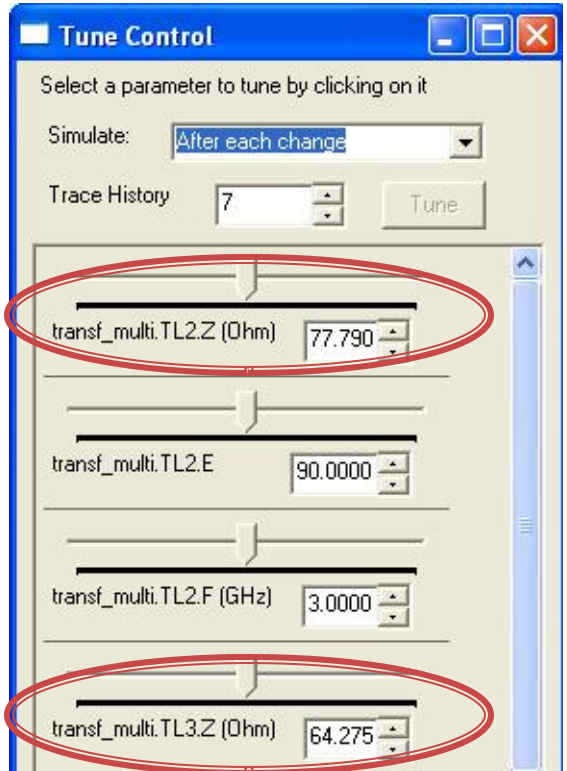
- During tune, due to frustration or haste, for the lines, the **frequencies** or **electrical lengths** are modified



- Always check (**permanently**) that the frequencies (**F**) electrical lengths (**E**) remain the correct ones (fo and 90) and only the impedance (**Z**) is tuned

Mistakes 6

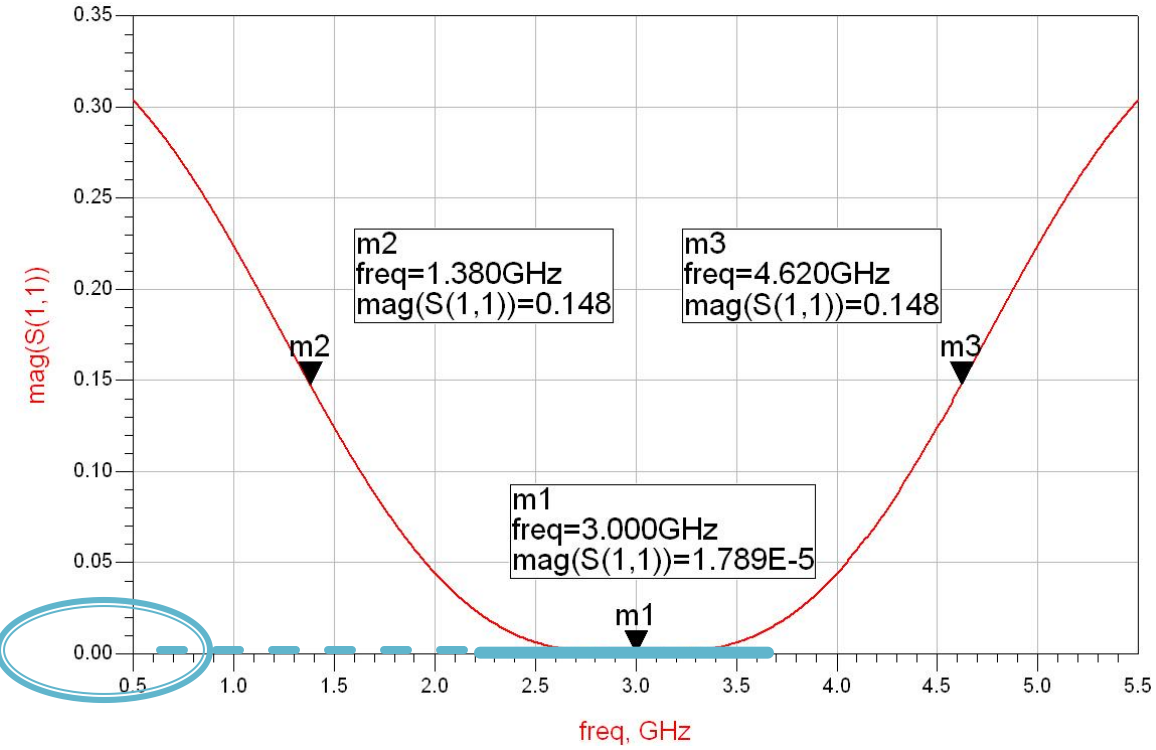
- During tune, the impedances are modified until the monotony rule is breached $Z_S > Z1 > Z2 > Z3 > Z_L$ **or** $Z_S < Z1 < Z2 < Z3 < Z_L$



- **Permanently check** that the 5 impedance values are either increasing or decreasing. The 3 transmission line values you tune must be in the **correct order and inside the interval** imposed by Z_S and Z_L

Mistakes 7

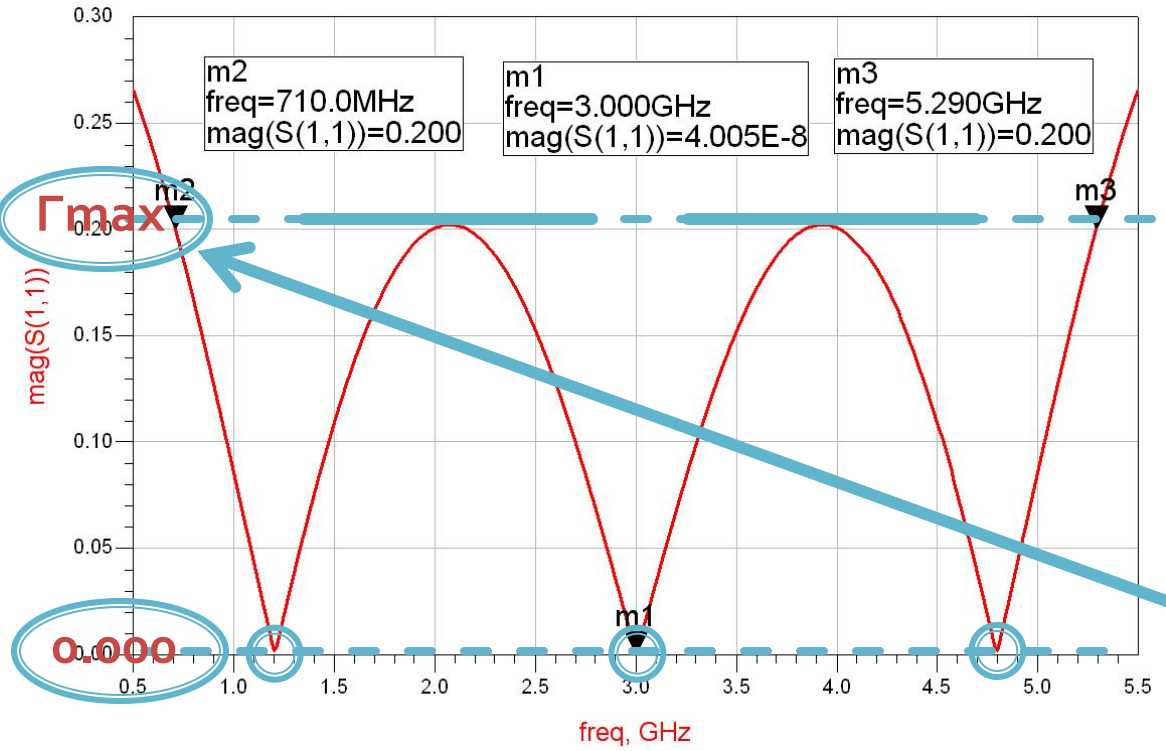
- You don't check the vertical axis against which the reflection coefficient is plotted.



- for the binomial transformer the graph **must not** be pointed/angled in fo but the tangent must be horizontal and reach **o.o** (or at least o.ooX)

Mistakes 8

- You don't check the vertical axis against which the reflection coefficient is plotted.



- for the Chebyshev transformer the graph **is** pointed and reaches **o.o** (or at least o.ooX) at **fo and at least two other frequencies** and the ripple inside the bandwidth reaches **Γmax** (from your individual subject)

Contact

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